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THE M. W. KELLOGG COMPANY
A division of Pullman Incorporated

MWKLG-RED-72-1268
DETAILED COST BREAKDOWN FOR SELECTED SULFUR OXIDE CONTROL PROCESSES

SUBMITTED TO
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS
CONTROL SYSTEMS DIVISION

TASK #7 FINAL REPORT

CONTRACT NO. CPA 70-68

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RESEARCH & ENGINEERING DEVELOPMENT

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Estimates were prepared for typical scrubbing processing areas, indicating capital costs attributable to scrubber, reheat, ductwork and fans. The control processes studied were selected to provide a range of different type gas scrubbing contactors, viz., packed column, multi-stage spray column, and one which contains beds of hollow plastic spheres. The results are presented of cost breakdowns made for the following control processes: magnesia base (slurry scrubbing, regenerable SO_2-H_2SO_4 by-product); wet limestone (slurry scrubbing, throwaway); citrate (solution scrubbing, regenerable, sulfur by-product); and ammonia scrubbing (solution scrubbing, regenerable, SO_2-H_2SO_4 by-product).

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TASK #7 FINAL REPORT

Submitted to

ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF AIR PROGRAMS

DIVISION OF CONTROL SYSTEMS

Contract No. CPA 70-68

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Chemical Engineering Development

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THE M.W. KELLOGG COMPANY
A DIVISION OF PULLMAN INCORPORATED

RESEARCH & ENGINEERING DEVELOPMENT

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by

THE M. W. KELLOGG COMPANY

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HOUSTON, TEXAS

March 17, 1972

I.D

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INTRODUCTION

Under Contract Number 70-68 awarded by the Environmental Protection Agency (EPA), Office of Air Programs (OAP), The M. W. Kellogg Company has been supplying engineering services comprising studies and evaluations of different aspects of air pollution control technology. Specific assignments are made via individual task orders. For example, under Task #5 specifications, preliminary process designs and economic evaluations were made of twelve different SO_2-control processes for power plant stack gases (final report PB-204711). In follow-up Task #6 Kellogg made an approximate parametric study of investment as a function of both the concentration of sulfur in the fuel (coal) and plant capacity for several control processes selected by EPA from the Task #5 group.

As a corollary to Task #6, EPA requested that Kellogg initiate detailed capital estimate breakdowns for some major processing steps in selected control processes. Again, the results of the Task #5 studies were to be used in making the investment breakdowns. As Phase I of Task #7, estimates were prepared for typical scrubbing processing areas, indicating capital costs attributable to scrubber, reheat, ductwork and fans. The control processes studied were selected to provide a range of different type gas scrubbing

contactors, viz., packed column, ~~Impinjet™ scrubber~~ (multi-stage spray column) and ~~Turbulent Contact Absorber~~, TCA™ (contains beds of hollow plastic spheres).

This report presents the results of cost breakdowns made for the following control processes selected by OAP:

- Magnesia Base (slurry scrubbing, regenerable SO_2-H_2SO_4 by-product)
- Wet Limestone (slurry scrubbing, throwaway)
- Citrate (solution scrubbing, regenerable, sulfur by-product)
- Ammonia Scrubbing (A) (solution scrubbing, regenerable, SO_2-H_2SO_4 by-product)

SUMMARY

Detailed investment cost breakdowns are presented for the individual processing steps in the scrubbing areas of the following pollution control processes for power plant stack gases:

- Magnesia Base
- Wet Limestone
- Citrate
- Ammonia (A)

These are four of the twelve processes for which preliminary process designs and economic evaluations were made under Task #5 of the same EPA contract. The cost estimates made during the Task #5 study served as the bases in breaking out the investment costs for the scrubbers, scrubber circuit, flue gas reheat circuit, induced draft fans, and ductwork, valves and expansion joints for the selected processes.

Table 1 summarizes the net investment costs for each of the categories considered. To arrive at figures for the incremental costs owing to the installation of the control plant "standard plant deductions" are subtracted from the total investment required for fans and ductwork for the combined power plant and control plant. The figures in Table 1 include these cost deductions.

Some general observations which can be made about the breakdown are: (1) The Citrate Process has the most expensive scrubber, a field-fabricated packed tower, while the

TABLE 1

NET INVESTMENT COST BREAKDOWN
(1000 MW - 3.5%S Coal)

Description	Magnesia Base	Wet Limestone	Citrate	Ammonia(A)
	← ($M) →			
Scrubber	3,460	3,620	4,620	2,920
Scrubber Circuit	6,810	6,130	7,930	4,450
Reheat Circuit	2,730	2,290	2,930	2,240
Fans	970	610	900	890
Ductwork, Valves & Expansion Joints	1,300	770	1,610	710

Impinjet™ scrubber used in the Ammonia (A) Scrubbing Process is the least expensive. The TCA Absorbers used in Magnesia Base and Wet Limestone Scrubbing are intermediate in cost; (2) The reheat systems are based on total carbon steel construction, while alloy construction probably will be needed for the gas cooler, thus adding $3-4 MM to the reheat system investments. Most likely, a different type of flue gas reheating system will be employed in any commercialization of the control processes; and (3) Control plants with two sets of scrubbers (venturis for fly ash removal and main scrubbers for sulfur oxide removal in Magnesia and Citrate Processes) require about twice as much investment for ductwork as do those which utilize the main scrubber for both fly ash and sulfur oxide removal (Wet Limestone and Ammonia).

As mentioned in the Task #5 final report (PB 204711) these preliminary investments for the various control processes should be viewed more on a comparative rather than on an individual basis, and this applies also to the results in this report. The sparsity of input information for many of the control processes and the limited effort authorized by the Task Order for the original study essentially limits the use of the results to process screening and program planning which were OAP's objectives.

BASES AND PROCEDURE FOR EVALUATION

The following four scrubbing processes were selected for evaluation in this study:

- Magnesia Base
- Wet Limestone
- Citrate
- Ammonia (A)

These four represent a cross-section of the different type scrubbing systems studied for Task #5. Table 2, "Characteristics of Selected Control Process", indicates that the four processes selected for study represent three types of absorbers: turbulent contact (TCA™) absorber, packed, and multi-stage spray column (Impinjet™); two types of scrubbing liquids: slurry and soluble; two types of ash/solids removal: venturi and main scrubber; and three types of by-product: sulfuric acid, elemental sulfur, and throwaway slurry. All processes have six trains of equipment treating the flue gas from a 1000 MW power plant burning 3.5% sulfur coal. Sulfur removal from the flue gas is at a nominal 90% and all four processes have systems for reheating the scrubbed flue gas.

The cost estimates made for the control processes for Task #5 were based on new plants (i.e., not retrofits) and battery limits only. In order to obtain investment figures attributable only to

TABLE 2

CHARACTERISTICS OF SELECTED CONTROL PROCESSES

Process	Type of Absorber	Scrubbing Liquid	Ash/Solids Removal	Type of By-Product
Magnesia Base	TCA™	Slurry	Venturi	Acid
Wet Limestone	TCA™	Slurry	Scrubber	Throwaway
Citrate	Packed	Soluble	Venturi	Sulfur
Ammonia (A)	Impinjet™	Soluble	Scrubber	Acid

Note: All processes have 6 trains and reheat systems.

the SO_2-control plant, certain "standard plant" deductions were made for fans and ductwork - i.e., equipment which would be required for any power plant, with or without a downstream pollution control system. This procedure has been followed also for the present study.

The four scrubbing systems considered were sub-divided as follows:

1. Scrubber
2. Scrubber Circuit
3. Reheat Circuit
4. Fans
5. Ductwork, Valves and Expansion Joints

The Appendix of this report contains flow sheets and equipment lists indicating the process equipment used for each of the above classifications.

The investment figures presented in the Task #5 final report were for the entire SO_2-control plant, including scrubbing section, scrubbing liquid recovery regeneration and sulfur by-product production where applicable. When considering each plant section alone, certain prorations had to be made based on the full plant investment. For example, it is very difficult to determine accurately the portion of start-up and contractor's fees that should be allocated to each of the processing sections.

As mentioned in the Task #5 final report, sufficient time, funds and input data were not available to permit a very detailed estimate of each process to be made. The major use of the results was expected to be in process screening and program planning by EPA-OAP, in which case the relative merits of the various processes would be of prime importance. Similarly, the Task #7 cost breakdown results should be viewed in this light.

DISCUSSION OF RESULTS

The tabulated results of the detailed cost breakdowns for the various processing steps for the four selected control processes are presented in the Appendix as Tables 4 - 7. The costs are broken down as follows:

1. Major Equipment Cost
2. Foundations, Concrete, Steel, Buildings, Paint and Insulation
3. Other Costs (Construction Forces, Home Office Engineering, Procurement, Insurance, Start-up, and Contractor's Fee)
4. Sub-Total Investment Cost (excl. standard plant deductions)
5. Net Investment Cost (includes standard plant deductions)

Sub-breakdowns include total direct materials costs and sub-contracts; also piping, electrical, and instrument costs are indicated.

Table 3 summarizes these individual costs by indicating the net investment for all four processes for each of the categories studied, viz., the scrubber, scrubber circuit, reheat circuit, fans, and ductwork, valves and expansion joints.

TABLE 3

NET INVESTMENT COST BREAKDOWN
(1000 MW - 3.5%S-Coal)

Description	Magnesia Base	Wet Limestone	Citrate	Ammonia (A)
	← ($M) →			
Scrubber	3,460	3,620	4,620	2,920
Scrubber Circuit	6,810	6,130	7,930	4,450
Reheat Circuit	2,730	2,290	2,930	2,240
Fans	970 (2,250)	610 (1,890)	900 (2,180)	890 (2,170)
Ductwork, Valves & Expansion Joints	1,300 (2,320)	770 (1,790)	1,610 (2,630)	710 (1,730)
Total Plant Investment*	26,800	10,800	21,200	16,200

( ) - excluding "standard plant deduction"

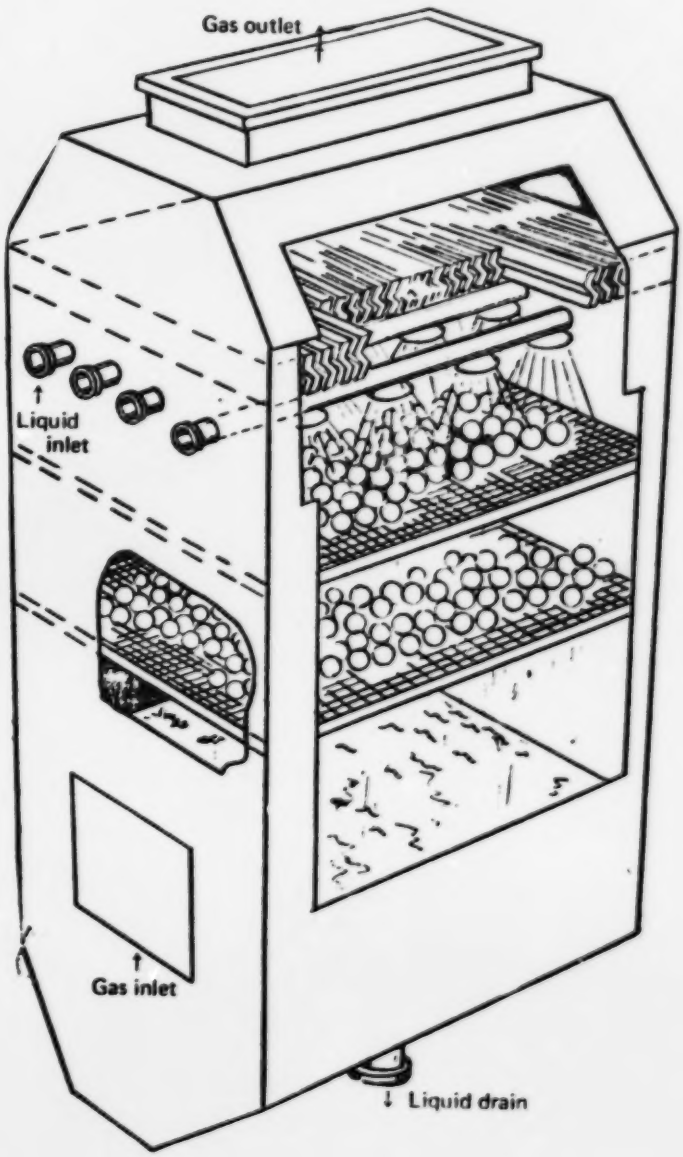
Scrubber

Three types of scrubbing devices are considered in this study. Magnesia Base and Wet Limestone Scrubbing use multi-bed turbulent contact absorbers, each stage containing an unrestrained bed of hollow plastic spheres (TCA™), designed and manufactured by Universal Oil Products Company, Air Correction Division. Figure 1 depicts a typical turbulent contact absorber scrubber. The Ammonia Scrubbing process utilizes a multi-staged perforated plate-impingement scrubber with separate circulation of liquor streams. The bottom stage is designed to have a high dust (fly ash) - removal efficiency. Figure 2 shows a standard Impinjet™ scrubber designed and manufactured by the W. W. Sly Manufacturing Company, and Figure 3 schematically depicts the scrubber design used in the Ammonia Scrubbing control process. Lastly, a standard design packed column is the scrubber used in the Citrate Process.

The investment figures presented in Table 3 for the scrubbers alone indicate that the packed tower absorber used in the Citrate Process is the most expensive, $4.62 MM. This is consistent with the high sub-contract costs for field fabrication of the large diameter towers. The TCA's™ for Magnesia and Wet Limestone Scrubbing, as expected, require the same investment, about $3.5 MM. The Ammonia Scrubbing Impinjet™ scrubber is the least costly, slightly less than $3 MM.

FIGURE 1

TYPICAL TURBULENT CONTACT ABSORBER SCRUBBER



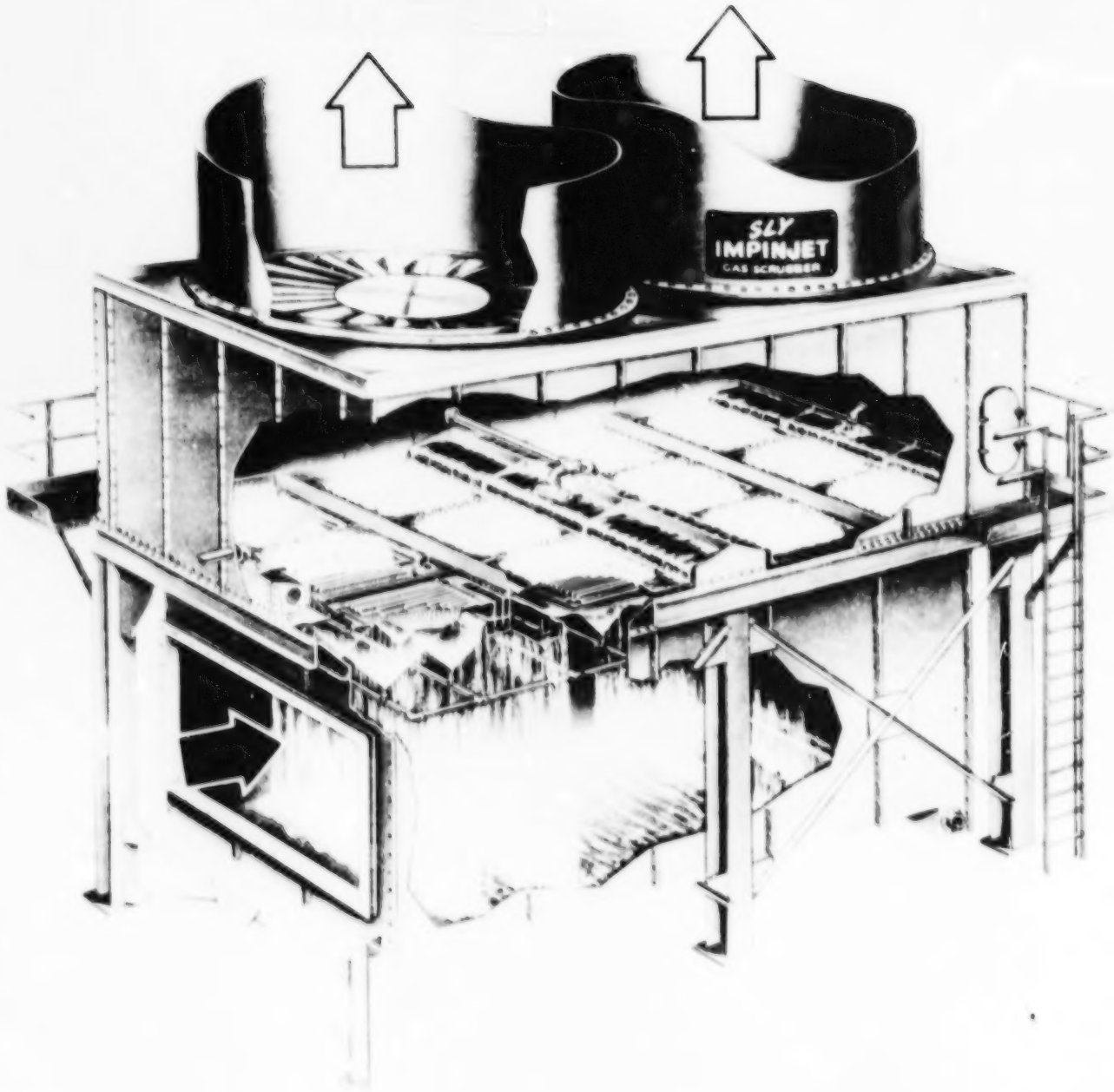
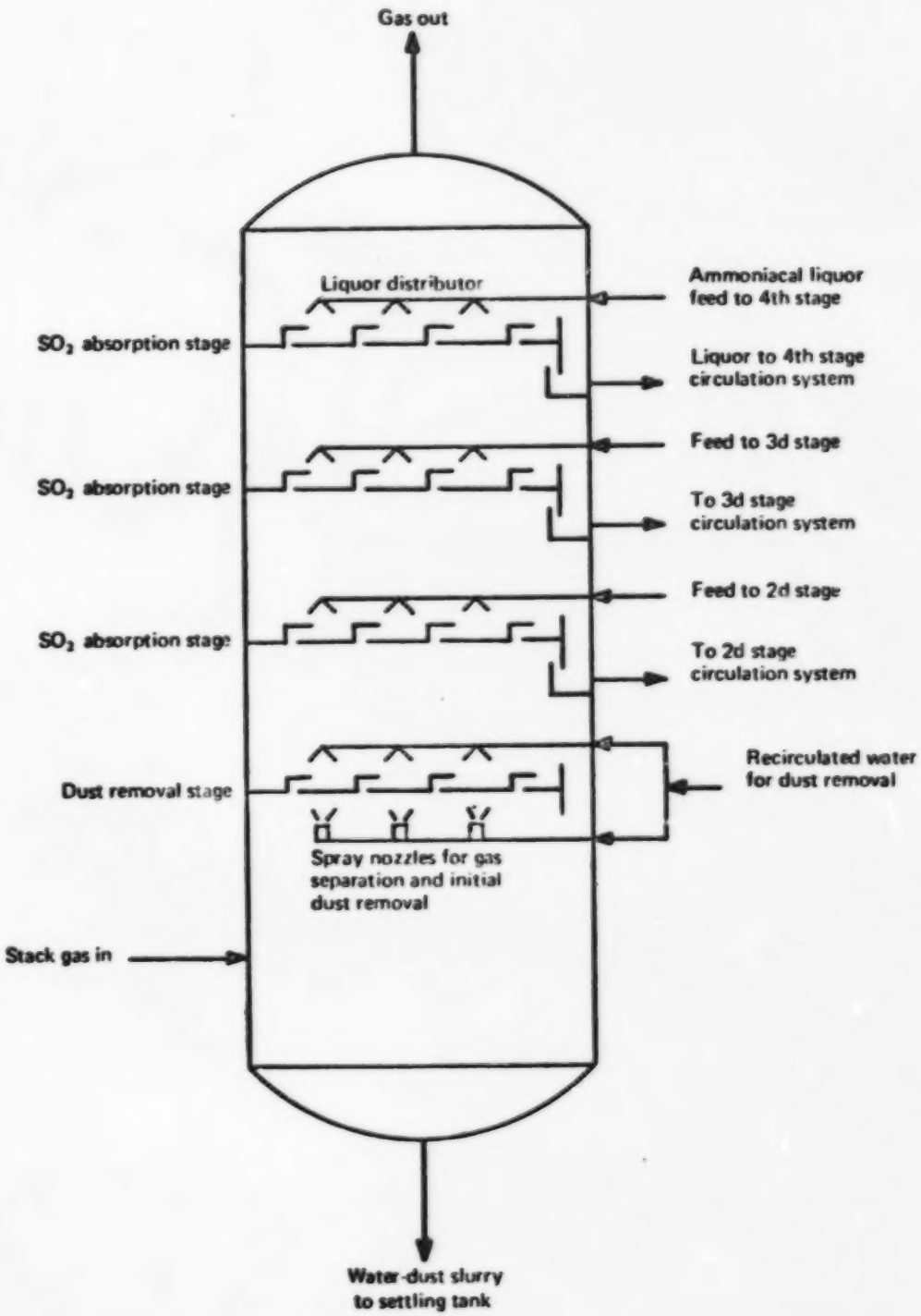

SLY
IMPINJET
GAS SCRUBBER

FIGURE 3

AMMONIA SCRUBBING (A) - SCHEMATIC OF IMPINJET SCRUBBER


Gas out
Liquor distributor
Ammoniacal liquor feed to 4th stage
SO_2 absorption stage
Liquor to 4th stage circulation system
Feed to 3d stage
SO_2 absorption stage
To 3d stage circulation system
Feed to 2d stage
SO_2 absorption stage
To 2d stage circulation system
Recirculated water for dust removal
Dust removal stage
Spray nozzles for gas separation and initial dust removal
Stack gas in
Water-dust slurry to settling tank

Scrubber Circuit

A cost breakdown also was made for the scrubbers including their auxiliary equipment. This scrubber circuit comprises the scrubbing liquid circulation piping, circulation pumps and tanks, and venturi scrubbers (where applicable). Ductwork for the flue gas is excluded.

The breakdown for the four control processes shows that the Citrate scrubbing equipment has the highest investment, $7.93 MM. This is reflected by the high field erection cost of the packed tower and the cost of venturi scrubbers which are required for fly ash removal from the flue gas before the latter enters the scrubbing tower. The MgO and Wet Limestone scrubbing circuits both use equivalent TCA^{TM} absorbers, but the Magnesia Base processing sequence is costlier ($6.81 vs. 6.13 MM) because it has Venturi scrubbers which represent a $1.2 MM sub-contract cost. The lower investment cost, $4.45 MM, for the Ammonia scrubbing section is due to the absence of venturis, a cheaper scrubber (Impinjet^{TM}), and a lower circulation rate requirement of scrubbing solution.

Reheat Circuit

All four control processes have systems for reheating the scrubbed flue gas from their saturated temperatures of about 120°F to 250°F. The basis for selecting the reheat system used

was a TVA study [1] in which five different stack gas reheat methods, where evaluated: (1) direct heating with natural gas (2) indirect heat exchange between the stack gas and a heat-transfer liquid, (3) indirect heat exchange between the gas streams before and after scrubbing, (4) indirect heating with steam (in a new power plant designed to produce excess steam), and (5) direct heating with cool in a stoker system. In accordance with TVA's conclusion, method (2) was used in making the process design for those SO_2-control plants requiring stack gas reheating. A closed loop circulation of water is used as the indirect heat exchange medium for cooling and reheating the flue gas. Materials of construction for both gas cooler and reheater were specified as carbon steel. As mentioned in the Task #5 final report, it was concluded that TVA's specification of carbon steel material of construction for the flue gas cooler located downstream from the air preheater is inadequate since the gas will be cooled below its dewpoint, thereby forming H_2SO_4 by the combination of SO_3 and water in the flue gas. A corrosion resistant material (e.g., Alloy 20) would be required for this corrosive service. Kellogg requested several heat exchanger vendors to quote prices for Alloy 20 exchangers of the large size required in the reheat circuits (about 250,000 ft^2 each).

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1 Sulfur Oxide Removal From Power Plant Stack Gases - Use of Limestone in Wet Scrubbing Process, TVA, Contract No. TV-29233A, 1969.

A reluctance by the vendors to quote any figures required Kellogg to stay with the cost estimate for carbon steel. A price for the alloy exchangers was finally received, but at too late a date to incorporate into plant cost investments. It was found that an additional $3-4 MM in investment would be necessary if Alloy 20 gas coolers are used. The costs presented in Table 3 for the four control processes' reheat systems, however, are for consistency with the Task #5 work, based on the original TVA evaluation, viz., both gas coolers and heaters are carbon steel with aluminum fins on the gas side.

The plant investments for the reheat systems (which includes the exchangers, water circulating pumps, tanks, and piping) range from $2.2 to $2.9 MM, the differences relating directly to slight differences in reheat levels and total flue gas handled for the different processes. For example, in the Magnesia Base scrubbing process the load on the exchangers is increased by the addition of flue gas from the magnesium sulfate reducer/calciner.

Fans

Induced draft fans are required in balanced draft power plants to draw the flue gases through the steam generation equipment and discharge it to the base of the stack. The standard power plant fans are estimated to supply a pressure differential of 20 inches of water which is needed to induce the flue gas to flow from the

boiler through the superheaters, reheaters, economizer, air preheater, and electrostatic precipitator. The pollution control plant requires additional fan horsepower due to pressure drop of the gas in scrubbers, exchangers, and ducts. In order to obtain a cost figure for fans attributable to the control process alone, the investment for the I.D. fans for the control process for the complete system (i.e., power plant and SO_2 control) is reduced by the amount needed for the standard power plant by itself. This allowance has been designated as the "standard plant deduction" which for a 1000 MW power plant is $1.28 MM. Thus, the total I.D. fan investment is reduced by this amount and the resulting net incremental investments for the SO_2-control processes shown in Table 3 range from $0.61 MM to $0.97 MM, the difference related directly to the overall pressure drop through the control process equipment.

Ductwork

This category comprises ductwork for the flue gases, expansion joints, and duct valves. As was done for the fans, a deduction is taken for the portion of ductwork that would be required in the standard power plant which does not have a pollution control system. A total of $1.02 MM is deducted from the total ductwork investment to arrive at a figure for the incremental cost owing to the installation of the control plant.

The net investment for ductwork for the Citrate Process and

Magnesia Base Scrubbing Process are $1.61 MM and $1.30 MM, respectively. The corresponding investments are $0.77 MM and $0.71 MM for Wet Limestone and Ammonia Scrubbing. The approximate ratio of two in investment for the two sets of processes is explained by the fact that Magnesia and Citrate require ducting for gas flow to/from venturi scrubbers and main scrubbers, while Wet Limestone and Ammonia have ductwork associated with flue gas transferred in and out of main scrubbers, only; i.e., no venturis.

APPENDIX

This Appendix includes:

1. An equipment list for each process and processing step studied.

2. Flow sheets for the following scrubbing process:
   - Magnesia Base (PD-118-D, 5/18/71)
   - Wet Limestone (PD-108-D, 5/21/71)
   - Citrate Process (PD-121-D, 5/24/71)
   - Ammonia (A) (PD-113-D, 5/19/71)

   The various processing steps considered in the cost breakdown are delineated on each flow sheet.

3. Tables 4 to 7, showing the detailed investment breakdowns for the selected processes.

EQUIPMENT LIST

MAGNESIA BASE:

Scrubber - E-1 A-F

Scrubbing Circuit - E-1 A-F, E-3 A-F, J-1 A-F, J-5 A-F, Piping; ex-ductwork

Reheat Circuit - C-1 A-F, C-2 A-F, F-2, J-4 A-F, Piping; ex-ductwork

Fans - J-3 A-F

Ductwork - Air Preheater to Stack, includes valves and expansion joints

WET LIMESTONE:

Scrubber - E-1 A-F

Scrubbing Circuit - E-1 A-F, F-5 A-F, J-1 A-F, Piping; ex-ductwork

Reheat Circuit - C-1 A-F, C-2 A-F, F-6, J-3 A, B, Piping; ex-ductwork

Fans - J-2 A-F

Ductwork - Air Preheater to Stack, includes valves and expansion joints

CITRATE:

Scrubber - E-2 A-F

Scrubbing Circuit - C-3 A-F, E-1A-F, E-2 A-F, J-3A-F, J-4 A-F, Piping; ex-ductwork

Reheat Circuit - C-1 A-F, C-2 A-F, F-12, J-2 A-F, Piping; ex-ductwork

Fans - J-1 A-F

Ductwork - Air Preheater to Stack, includes valves and expansion joints

EQUIPMENT LIST (CONTINUED)

AMMONIA SCRUBBING (A):

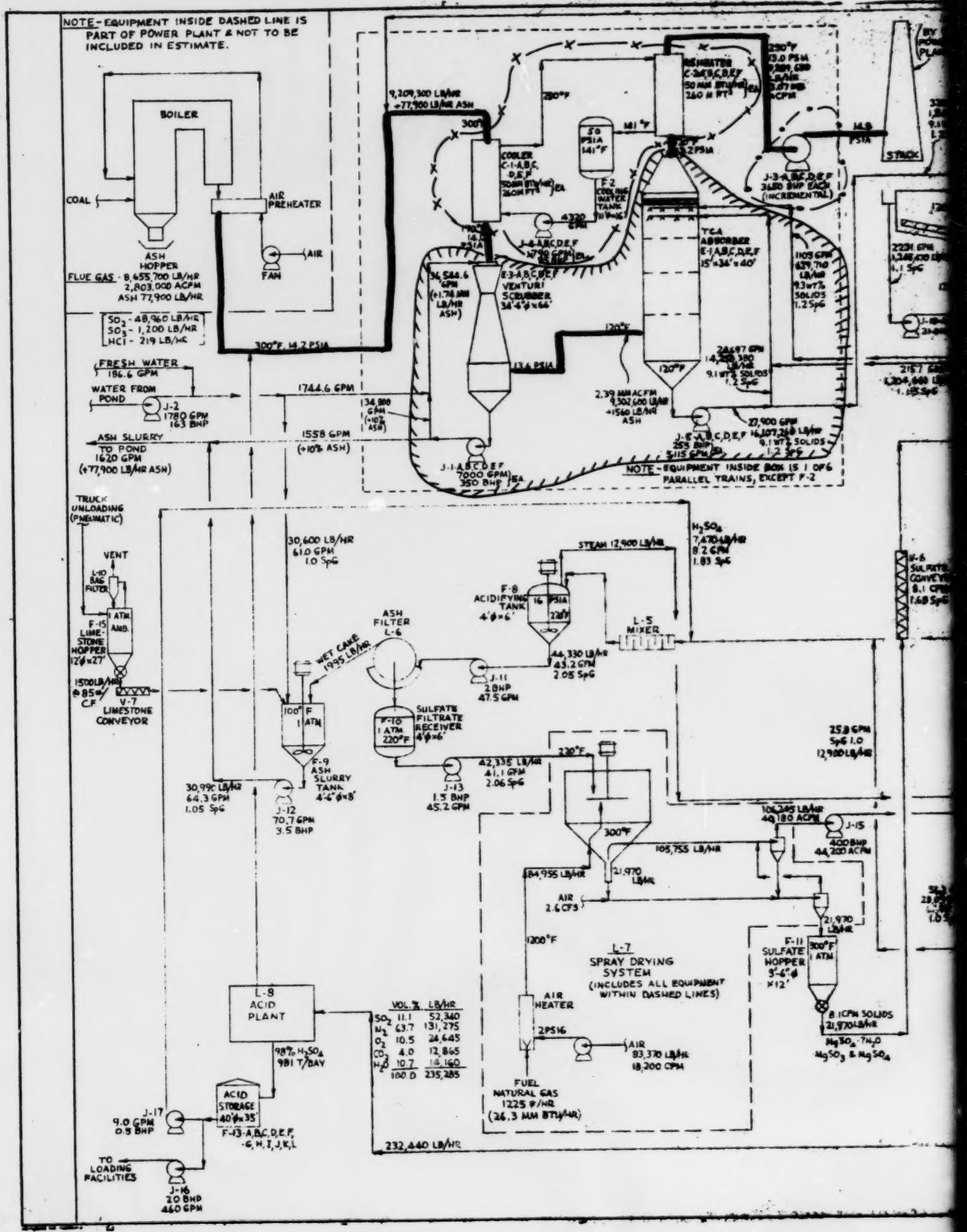
Scrubber - E-1 A-F

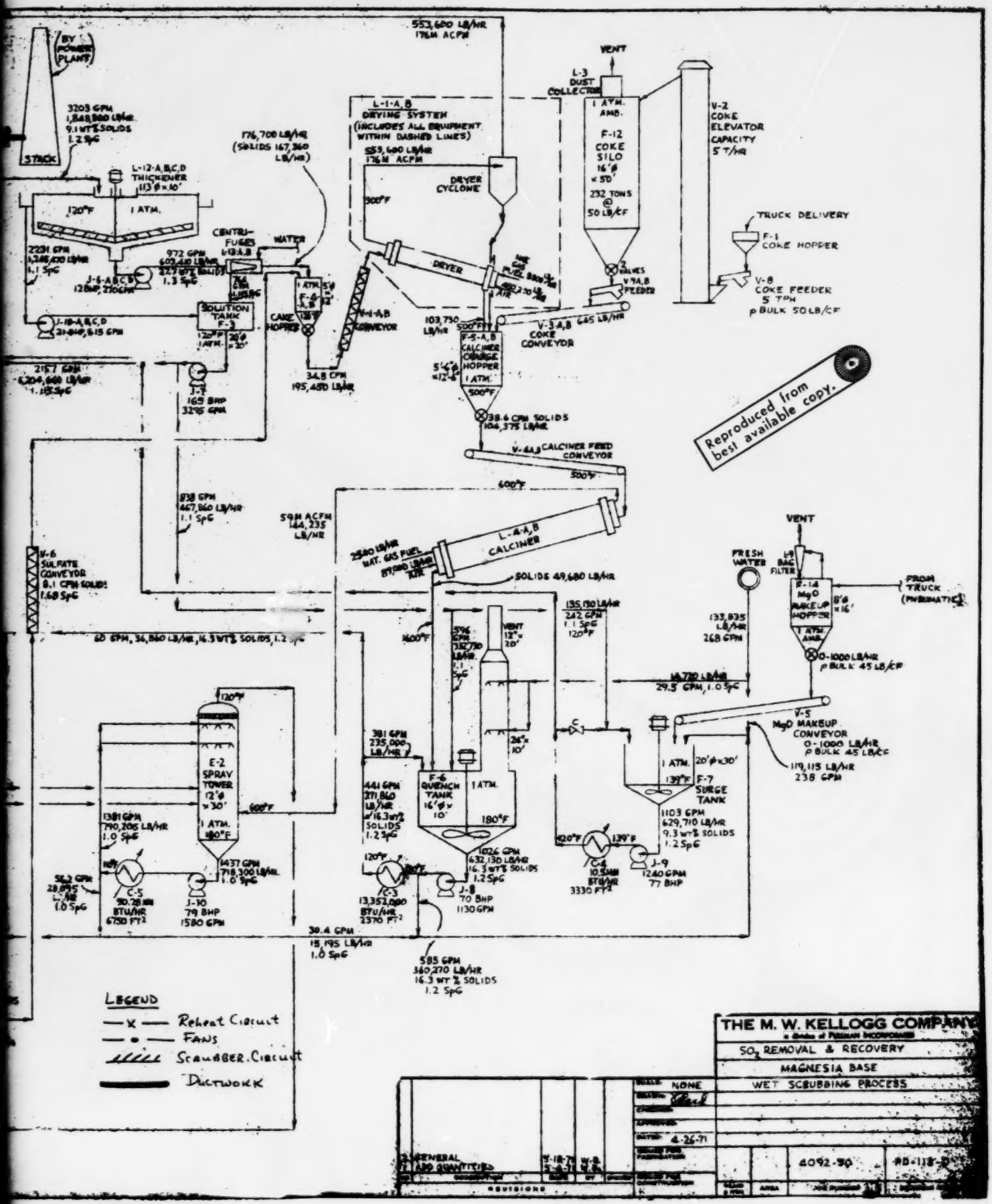
Scrubbing Circuit - E-1 A-F, F-1 A, B, F-2 A, B, F-3 A, B, J-1 A, B, J-2, A, B, J-3 A, B, J-4 A, B, J-6 A, B.

Reheat Circuit - C-1 A-F, C-2 A-F, F-5, J-8 A, B, Piping; ex-ductwork

Fans - J-9 A-F

Ductwork - Air Preheater to Stack, includes valves and expansion joints.


NOTE - EQUIPMENT INSIDE DASHED LINE IS PART OF POWER PLANT & NOT TO BE INCLUDED IN ESTIMATE.
BOILER
COAL
AIR PREHEATER
AIR
FAN
ASH HOPPER
FLUE GAS - 8,655,700 LB/HR 2,803,000 ACFM ASH 77,900 LB/HR
SO_2 - 48,960 LB/HR
SO_3 - 1,200 LB/HR
HCl - 219 LB/HR
300°F, 14.2 PSIA
FRESH WATER 186.6 GPM
WATER FROM POND
J-2 1780 GPM 163 BHP
1744.6 GPM
ASH SLURRY TO POND 1620 GPM (477,900 LB/HR ASH)
1558 GPM (+10% ASH)
9,209,300 LB/HR +77,900 LB/HR ASH
300°
280°F
REHEATER C-1A,B,C,D,E,F 50 MM BTU/HR 260 M FT²
230°F 13.0 PSIA 9,289,630 LB/HR 3,677 MM ACFM
14.9 PSIA
STACK
COOLER C-1-A,B,C, D,E,F 50 MM BTU/HR 260M FT²
50 PSIA 141°F
F-2 COOLING WATER TANK 31'Ø×16'
181°F
4220 GPM
J-4-A,B,C,D,E,F 4730 GPM 350 BHP EA
J-3-A,B,C,D,E,F 3480 BHP EACH (INCREMENTAL)
TCA ABSORBER E-1A,B,C,D,E,F 15'×34'×40'
1103 GPM 629,710 LB/HR 9.3 WT% SOLIDS 1.2 SpG
E-3-A,B,C,D,E,F VENTURI SCRUBBER 34'6"Ø×64'
34,544.6 GPM (+1.74 MM LB/HR ASH)
13.6 PSIA
120°F
2.39 MM ACFM 9,302,600 LB/HR +1560 LB/HR ASH
24697 GPM 14,288,390 LB/HR 9.1 WT% SOLIDS 1.2 SpG
27,900 GPM 16,107,260 LB/HR 9.1 WT% SOLIDS 1.2 SpG
J-5-A,B,C,D,E,F 253 BHP 3115 GPM EA
J-1 A,B,C,D,E,F 7000 GPM 350 BHP 1 EA
NOTE - EQUIPMENT INSIDE BOX IS 1 OF 6 PARALLEL TRAINS, EXCEPT F-2
TRUCK UNLOADING (PNEUMATIC)
VENT
L-10 BAG FILTER
F-15 LIME-STONE HOPPER 12'Ø×27'
1 ATM AMB.
1500 LB/HR @ 85% C.F
V-7 LIMESTONE CONVEYOR
30,600 LB/HR 61.0 GPM 1.0 SpG
ASH FILTER L-6
WET CAKE 1995 LB/HR
F-9 ASH SLURRY TANK 4'-6"Ø×8'
100°F 1 ATM
30,990 LB/HR 64.3 GPM 1.05 SpG
J-12 70.7 GPM 3.5 BHP
F-10 1 ATM 220°F SULFATE FILTRATE RECEIVER 4'Ø×6'
42,335 LB/HR 41.1 GPM 2.06 SpG
J-13 1.5 BHP 45.2 GPM
J-11 2 BHP 47.5 GPM
44,330 LB/HR 43.2 GPM 2.05 SpG
F-8 ACIDIFYING TANK 4'Ø×6'
16 PSIA 220°F
STEAM 12,900 LB/HR
H_2SO_4 7,470 LB/HR 8.2 GPM 1.83 SpG
L-5 MIXER
25.8 GPM SpG 1.0 12,900 LB/HR
230°F
300°F
106,345 LB/HR 49,180 ACFM
J-15 400 BHP 44,220 ACFM
105,755 LB/HR
84,955 LB/HR
21,970 LB/HR
AIR 2.6 CFS
1200°F
L-7 SPRAY DRYING SYSTEM (INCLUDES ALL EQUIPMENT WITHIN DASHED LINES)
AIR HEATER
12 PSIG
AIR 83,370 LB/HR 18,200 CFM
FUEL NATURAL GAS 1225 #/HR (26.3 MM BTU/HR)
F-11 SULFATE HOPPER 5'-6"Ø ×12'
300°F 1 ATM
8 TON SOLIDS 21,970 LB/HR
$MgSO_3 \cdot 7H_2O$ $MgSO_3$ & $MgSO_4$
L-8 ACID PLANT
98% H_2SO_4 981 T/DAY
VOL.% LB/HR
SO_2 11.1 52,340
N_2 63.7 131,275
O_2 10.5 24,645
CO_2 4.0 12,865
H_2O 10.7 16,160
100.0 235,285
232,440 LB/HR
ACID STORAGE 40'Ø×35'
F-13-A,B,C,D,E,F, -G,H,I,J,K,L
J-17 9.0 GPM 0.5 BHP
TO LOADING FACILITIES
J-16 20 BHP 460 GPM



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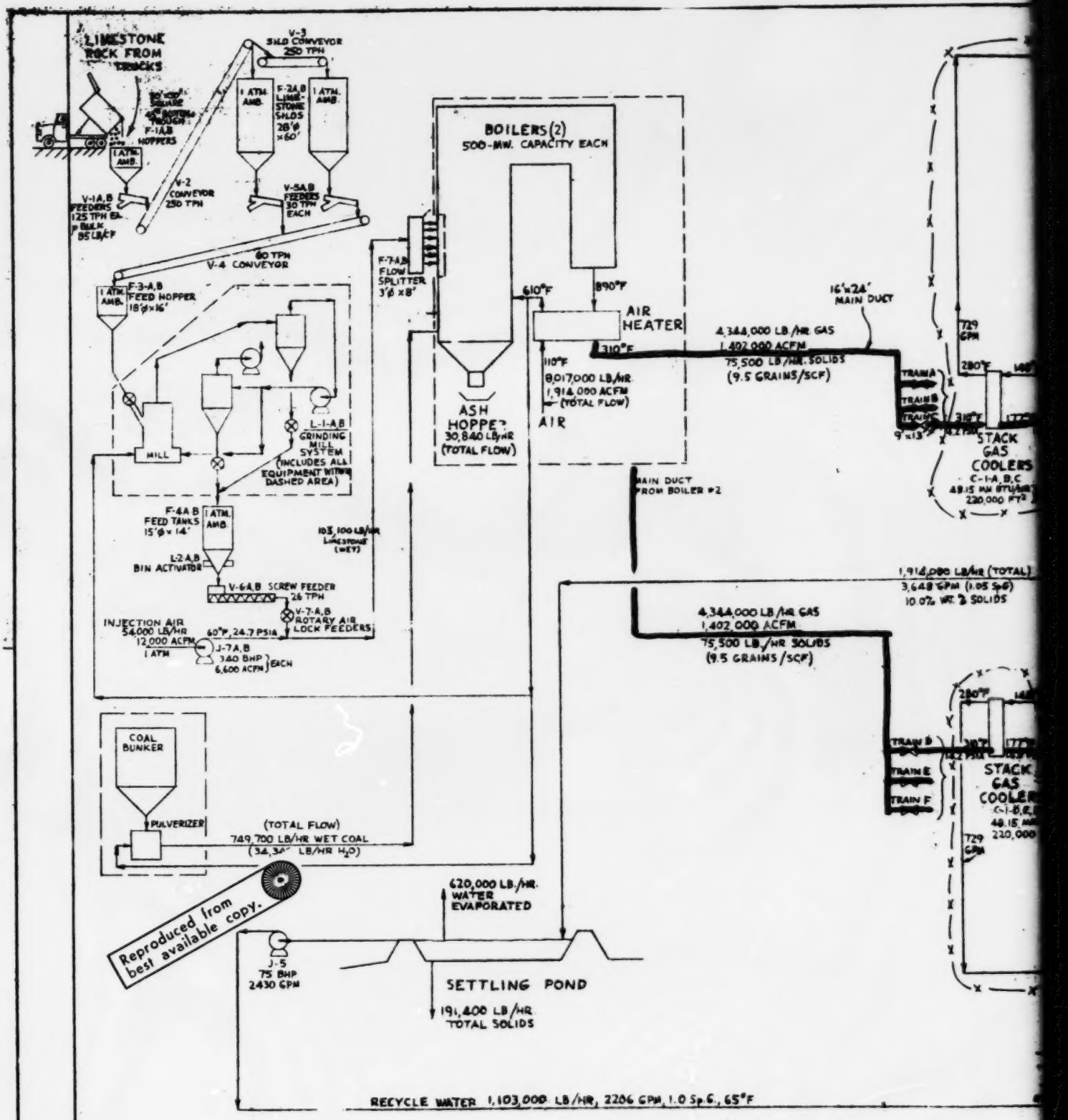

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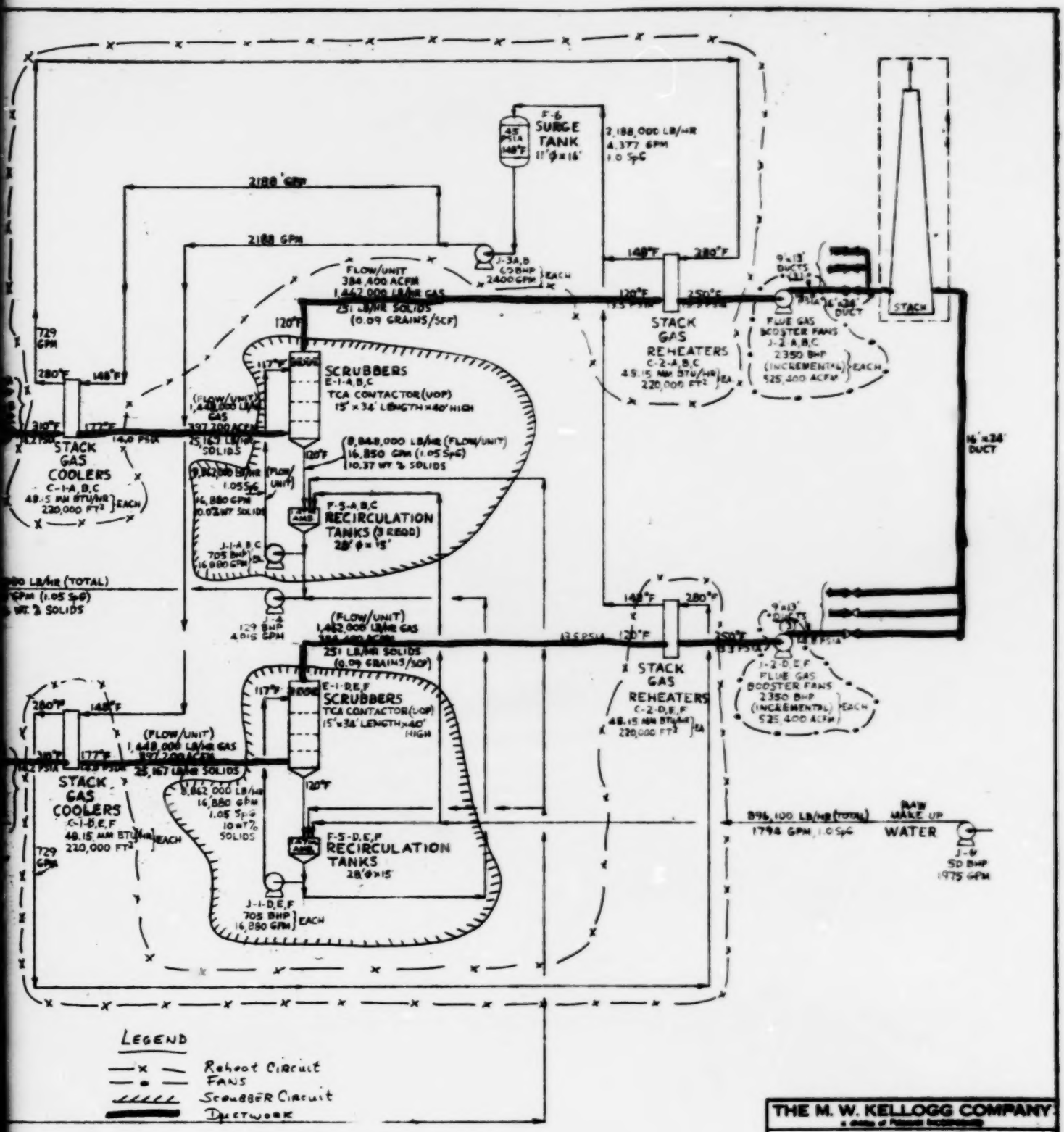

F-6 SURGE TANK 11'Ø x 16'
45 PSIA 148°F
2,188,000 LB/HR
4,377 GPM
1.0 SpG
2188 GPM
J-3A,B 60 BHP 2400 GPM EACH
FLOW/UNIT 384,400 ACFM 1,462,000 LB/HR GAS 251 LB/HR SOLIDS (0.09 GRAINS/SCF)
729 GPM
280°F
148°F
120°F
250°F
STACK GAS REHEATERS C-2-A,B,C 49.15 MM BTU/HR 220,000 FT² EA
FLUE GAS BOOSTER FANS J-2 A,B,C 2350 BHP (INCREMENTAL) 525,400 ACFM EACH
9'x13' DUCTS
16'x28' DUCT
STACK
SCRUBBERS E-1-A,B,C TCA CONTACTOR (VDP) 15'x34' LENGTH x 40' HIGH
(FLOW/UNIT) 1,448,000 LB/HR GAS 397,200 ACFM 25,167 LB/HR SOLIDS
14.0 PSIA
9,848,000 LB/HR (FLOW/UNIT) 16,850 GPM (1.05 SpG) 10.37 WT % SOLIDS
9,842,000 LB/HR (FLOW/UNIT) 1.05 SpG 16,880 GPM 10.02 WT % SOLIDS
STACK GAS COOLERS C-1-A,B,C 49.15 MM BTU/HR 220,000 FT² EACH
F-5-A,B,C RECIRCULATION TANKS (3 REQD) 28'Ø x 15'
J-1-A,B,C 705 BHP 16,880 GPM
J-4 129 BHP 401 GPM
(FLOW/UNIT) 1,462,000 LB/HR GAS 384,400 ACFM 251 LB/HR SOLIDS (0.09 GRAINS/SCF)
STACK GAS REHEATERS C-2-D,E,F 48.15 MM BTU/HR 220,000 FT² EA
J-2-D,E,F FLUE GAS BOOSTER FANS 2350 BHP (INCREMENTAL) 525,400 ACFM EACH
E-1-D,E,F SCRUBBERS TCA CONTACTOR (LOP) 15'x34' LENGTH x 40' HIGH
(FLOW/UNIT) 1,448,000 LB/HR GAS 397,200 ACFM 25,167 LB/HR SOLIDS
STACK GAS COOLERS C-1-D,E,F 48.15 MM BTU/HR 220,000 FT² EACH
9,842,000 LB/HR 16,880 GPM 1.05 SpG 10 WT% SOLIDS
F-5-D,E,F RECIRCULATION TANKS 28'Ø x 15'
J-1-D,E,F 705 BHP 16,880 GPM EACH
896,100 LB/HR (TOTAL) 1794 GPM, 1.0 SpG
RAW MAKE UP WATER
J-6 50 BHP 1975 GPM

LEGEND

- Reheat Circuit
- Fans
- Scrubber Circuit
- Ductwork

NOTES

1. EQUIPMENT SHOWN WITHIN DASHED LINES NOT INCLUDED IN PROCESS ESTIMATE, (EXCEPT L-1-A,B)
2. INCREMENTAL POND AREA REQUIRED FOR 10 YEAR STORAGE OF LIMESTONE REACTION PRODUCTS IS 2,050 ACRE-FEET.

ISSUE DATE 3-29-71

5	GENERAL	5-21-71	W B		
4	CHANGED TO SINGLE STACK	3-29-71	W B	L J S	
3	GENERAL	3-25-71	W B	L J S	
2	ADD NOMENCLATURE	3-16-71	W B	L J S	
1	ADD QUANTITIES	2-9-71	W B	L J S	
NO.	DESCRIPTION	DATE	BY	CHECKED	

REVISIONS

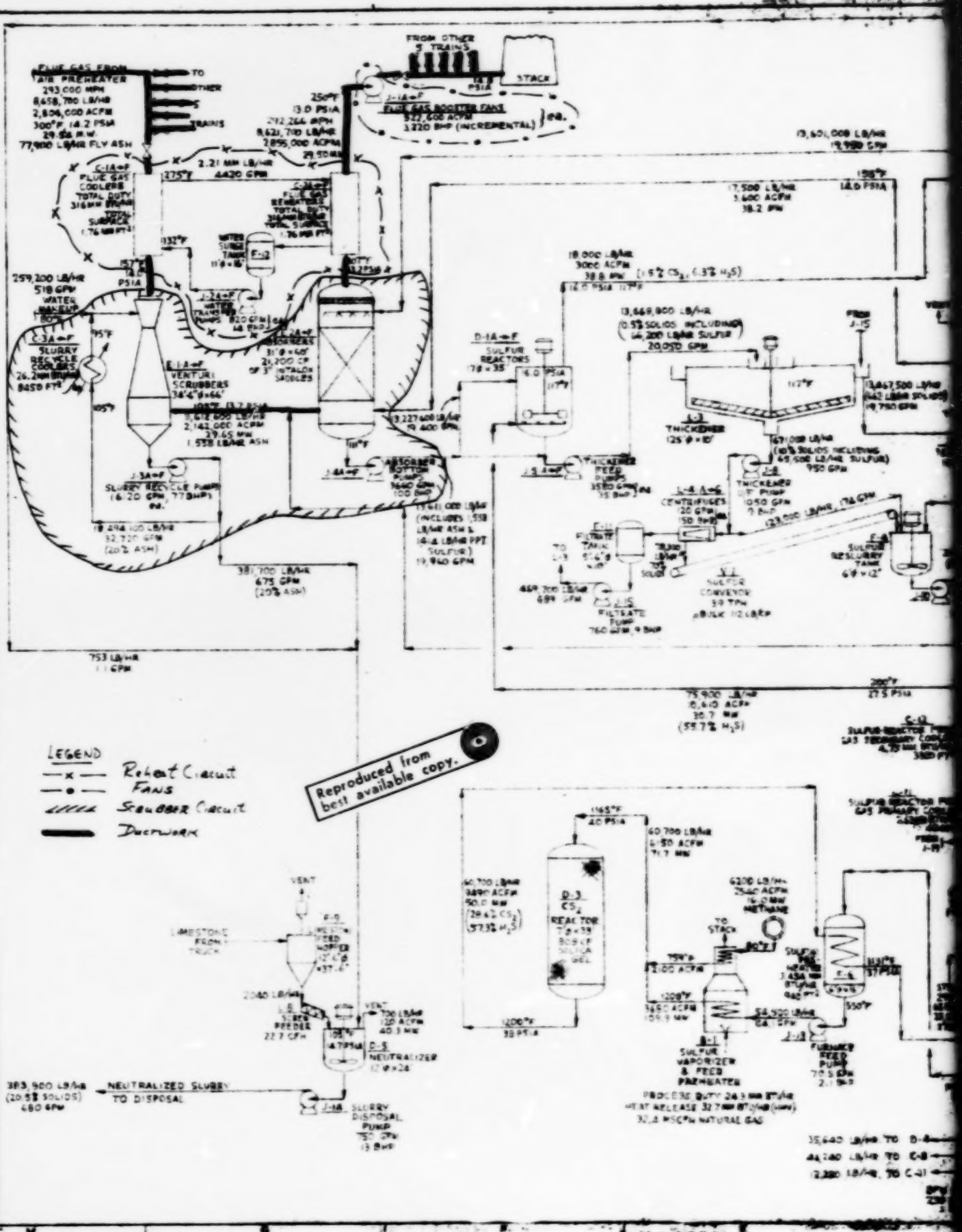
SCALE NONE
DRAWN W B
CHECKED
APPROVED 1-27-71
DATE
SUPERSEDES
SUPERSEDED BY

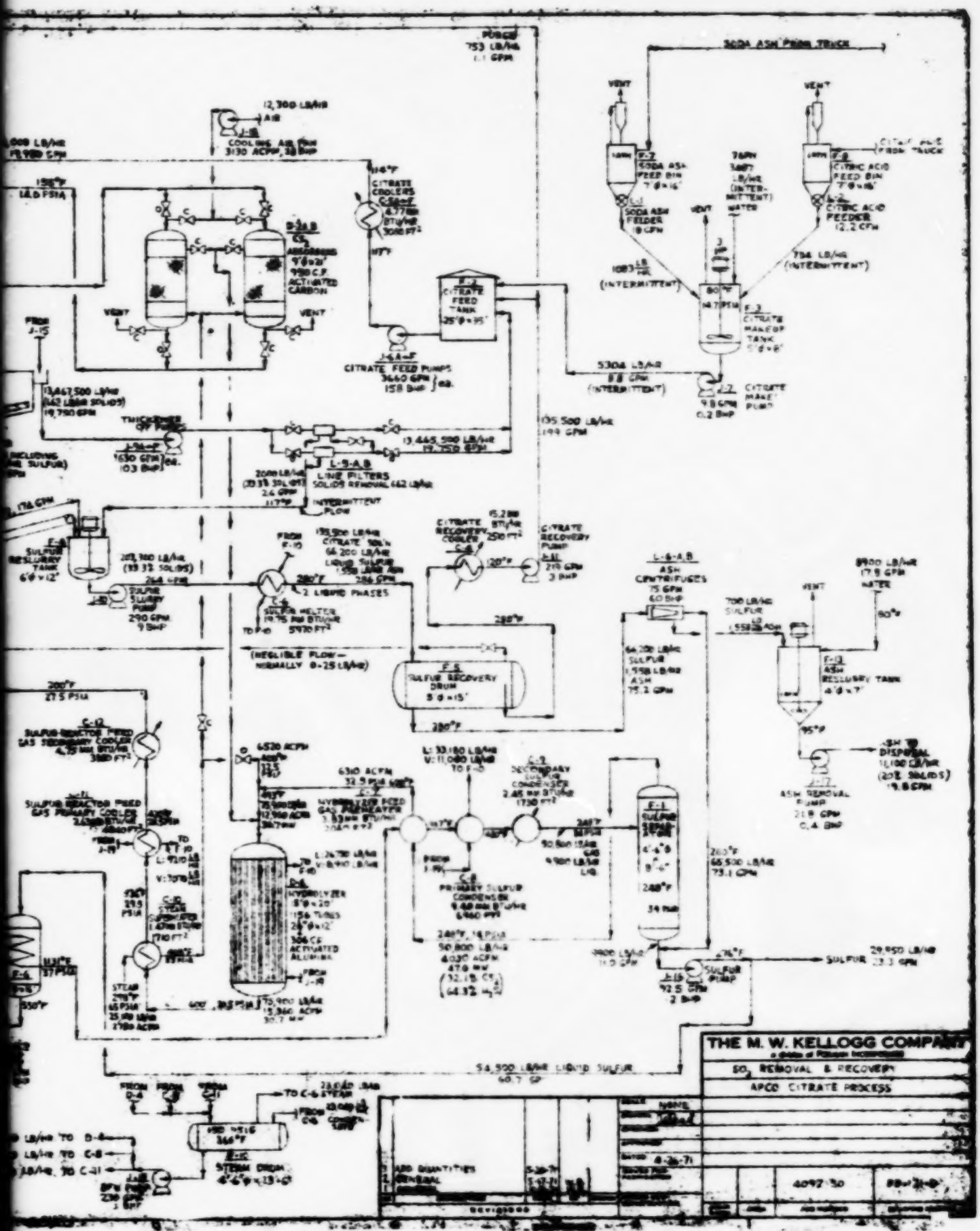
THE M. W. KELLOGG COMPANY
a Divisions of Pullman Incorporated

STEAM POWER PLANT SULFUR OXIDE CONTROL
WET LIMESTONE PROCESS
NEW 1000 MEGAWATT INSTALLATION

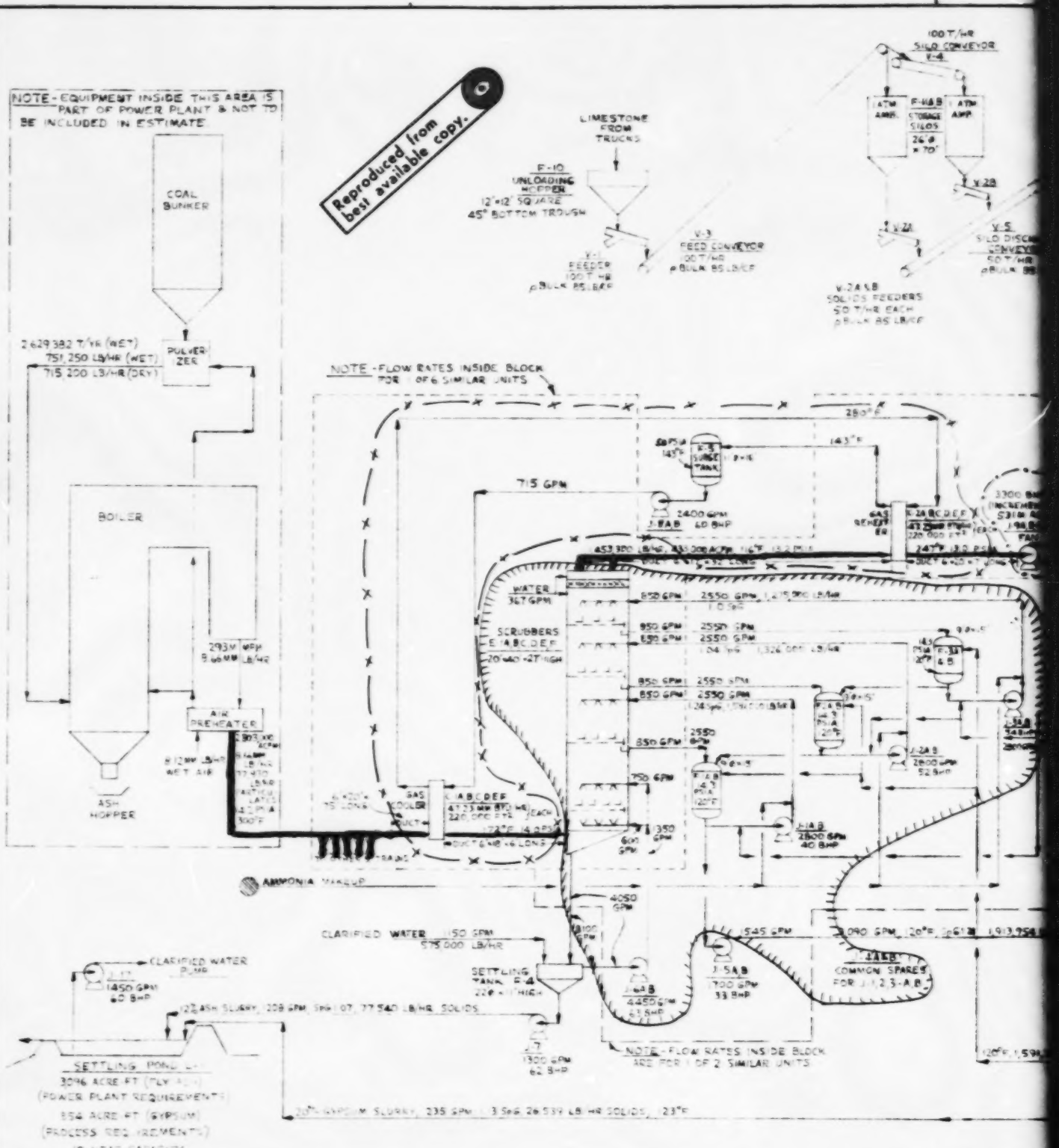
4092-50 PD-108-B

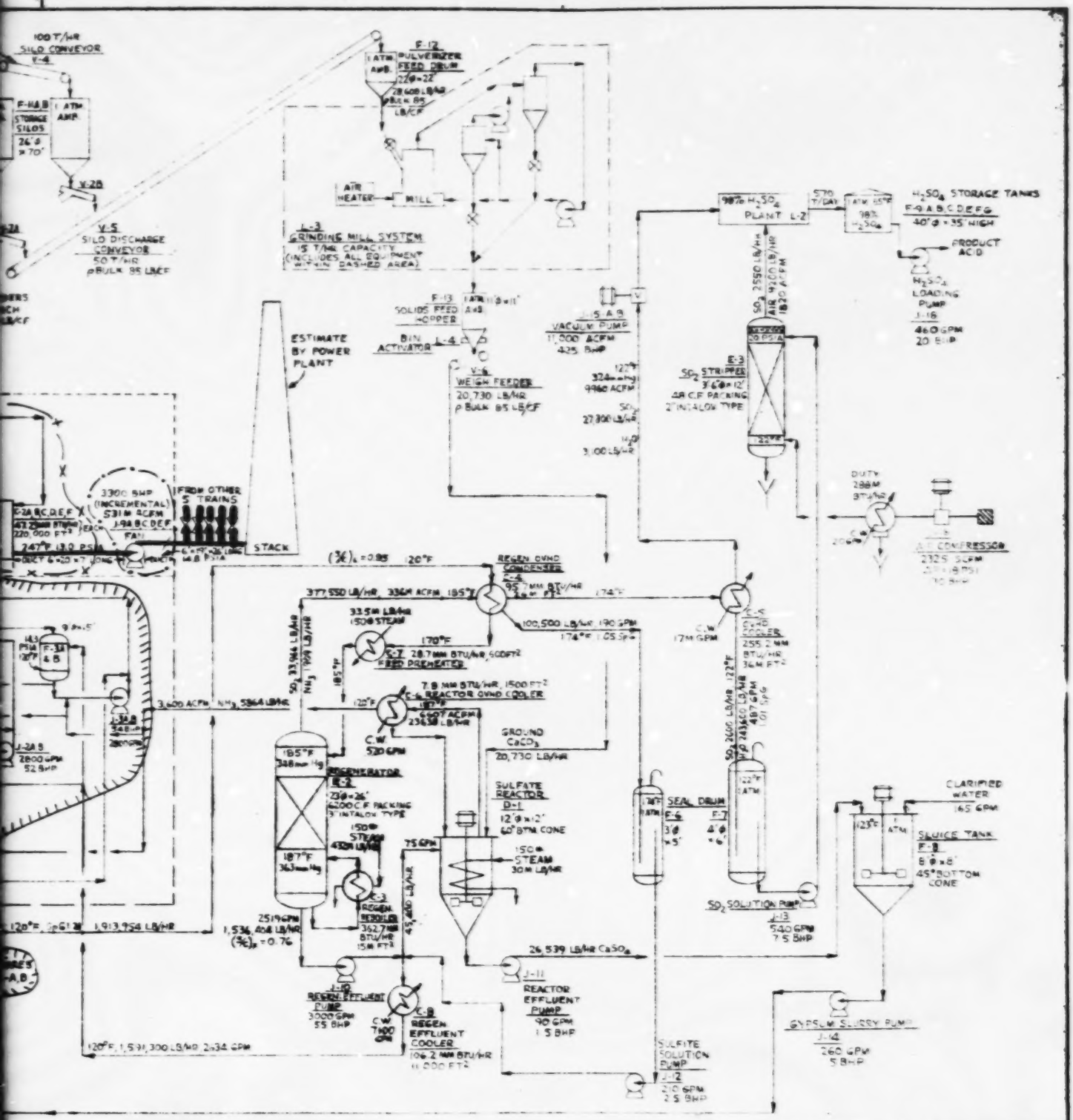
B


FROM OTHER 5 TRAINS
STACK
FLUE GAS FROM AIR PREHEATER
293,000 MPH
8458,700 LB/HR
2,804,000 ACFM
300°F 14.2 PSIA
29.5± MW
77,900 LB/HR FLY ASH
TO OTHER 5 TRAINS
C-1A or F FLUE GAS COOLER/REHEATER
TOTAL DUTY 316MM BTU/HR
TOTAL SURFACE 1.76 MM FT²
2.21 MM LB/HR
275°F 4420 GPM
FLUE GAS BOOSTER FANS
527,600 ACFM
3220 BHP (INCREMENTAL)
250°F
13.0 PSIA
292,266 MPH
8621,700 LB/HR
2895,000 ACFM
29.50 MW
13,601,000 LB/HR
19,950 GPM
132°F
259,200 LB/HR
518 GPM
WATER
C-3A or F SLURRY RECYCLE COOLERS
26.2MM BTU/HR
8458 FT²
95°F
105°F
E-1A or F VENTURI SCRUBBERS
34'-4" x 66'
2,142,000 ACFM
29.65 MW
1,558 LB/MM ASH
J-3A or F SLURRY RECYCLE PUMPS
(6,120 GPM, 775HP) 6#.
18,494,100 LB/HR
32,720 GPM
(20% ASH)
381,700 LB/HR
675 GPM
(20% ASH)
753 LB/HR
1.1 GPM
J-2A or F WATER TRANSFER PUMPS
820 GPM
48 BHP
E-2A or F ABSORBER RECIRCULATION TANKS
31'0" x 60'
21,200 CF
3" INTALOX SADDLES
J-4A or F ABSORBER RECIRCULATION PUMPS
3660 GPM
100 BHP
13,611,000 LB/HR
(INCLUDES 1,558 LB/HR ASH & 14.4 LB/MM PPT SULFUR)
19,960 GPM
17,500 LB/HR
3,600 ACFM
38.2 MW
138°F
14.0 PSIA
18,000 LB/HR
3000 ACFM
38.8 MW (1.5% CS_2, 1.3% H_2S)
16.0 PSIA 117°F
D-1A or F SULFUR REACTORS
78 x 35'
16.0 PSIA
117°F
13,669,800 LB/HR
(0.5% SOLIDS INCLUDING 44,200 LB/HR SULFUR)
20,050 GPM
FROM J-15
117°F
J-3 THICKENER
125 x 15'
3,667,500 LB/HR
(4.2% SOLIDS INCLUDING 154,000 LB/HR SULFUR)
(9,750 GPM)
67,000 LB/HR
(10% SOLIDS INCLUDING 44,500 LB/HR SULFUR)
950 GPM
J-5 A or F THICKENER FEED PUMPS
3550 GPM
35 BHP
J-6 THICKENED U/F PUMP
1050 GPM
9 BHP
L-4 A or F CENTRIFUGES
20 GPM
50 BHP
123,000 LB/HR, 178 GPM
F-11 FILTRATE TANK
9'-6" x 10'
TO J-15
J-7 J-15 FILTRATE PUMPS
760 GPM, 9 BHP
469,300 LB/HR
699 GPM
L-1 SULFUR CONVEYOR
39 TPH
(BULK 112 LB/FT³)
F-8 SULFUR RESLURRY TANK
6'9" x 12'
75,900 LB/HR
8,610 ACFM
30.7 MW
(55.7% H_2S)
200°F
27.5 PSIA
C-12 SULFUR REACTOR TUBE GAS TEMPERATURE CONTROL
4.75 MM BTU/HR
3500 FT²
LEGEND
Reheat Circuit
FANS
Scrubber Circuit
Ductwork
Reproduced from best available copy.
1165°F
40 PSIA
60,700 LB/HR
4150 ACFM
71.7 MW
D-3 CS_2 REACTOR 7'9" x 38' BOILER SULFUR FUEL
60,700 LB/HR
3891 ACFM
50.0 MW
(28.2% CS_2)
(57.3% H_2S)
1200°F
38 PSIA
6200 LB/HR
2540 ACFM
14.0 MW
METHANE
TO STACK
802°F
759°F
2,000 ACFM
1208°F
1660 ACFM
109.9 MW
54,500 LB/HR
64 GPM
550°F
J-13 FURNACE FEED PUMP
79.5 GPM
2.1 BHP
B-1 SULFUR VAPORIZER & FEED PREHEATER
PROCESS DUTY 24.3 MM BTU/HR
HEAT RELEASE 32.7 MM BTU/HR (LHV)
30.2 MSCFM NATURAL GAS
35,640 LB/HR TO D-8
44,280 LB/HR TO C-8
2,380 LB/HR TO C-11
VENT
F-9 LIMESTONE FEED HOPPER
12'-6" x 37'-6"
LIMESTONE FROM TRUCK
2040 LB/HR
G-5 SCREW FEEDER
22.7 CFM
VENT
720 LB/HR
120 ACFM
40.3 MW
D-5 NEUTRALIZER
17 x 24
383,900 LB/HR
(20.5% SOLIDS)
480 GPM
NEUTRALIZED SLURRY TO DISPOSAL
J-14 SLURRY DISPOSAL PUMP
55 GPM
9 BHP


PURGE
753 LB/HR
SODA ASH FROM TRUCK
VENT
CITRIC ACID FROM TRUCK
12,300 LB/HR AIR
COOLING AIR FAN
3130 ACFM, 10 BHP
CITRATE COOLERS
C-5 & C-7
4,777 BTU/HR FT²
ABSORBERS
9'Ø x 21'
990 C.F. ACTIVATED CARBON
D-5 A & B
VENT
FROM J-15
SODA ASH FEED BIN
7'Ø x 16'
F-7
SODA ASH FEEDER
8 CFM
J-11
76 GPM
3487 LB/HR (INTERMITTENT)
WATER
CITRIC ACID FEED BIN
7'Ø x 16'
F-8
CITRIC ACID FEEDER
12.2 CFM
J-12
734 LB/HR (INTERMITTENT)
1083 LB/HR (INTERMITTENT)
CITRATE FEED TANK
25'Ø x 35'
F-2
CITRATE MAKEUP TANK
5'Ø x 8'
F-3
CITRATE FEED PUMPS
3660 GPM
158 BHP
J-6 A-F
5304 LB/HR
8.8 GPM
(INTERMITTENT)
CITRATE MAKE UP PUMP
9.8 GPM
0.2 BHP
J-7
13,667,500 LB/HR
(462 LB/HR SOLIDS)
19,790 GPM
THICKENER U/F PUMPS
1650 GPM
103 BHP
J-14 A-F
13,445,500 LB/HR
19,700 GPM
135,500 LB/HR
199 GPM
2000 LB/HR
(0.35 SOLIDS)
24 GPM
LINE FILTERS
SOLIDS REMOVAL 462 LB/HR
L-5 A,B
INTERMITTENT FLOW
SULFUR RESLURRY TANK
6'Ø x 12'
F-9
203,300 LB/HR
(33.32 SOLIDS)
264 GPM
SULFUR SLURRY PUMP
290 GPM
9 BHP
J-10
CITRATE RECOVERY COOLER
C-6
15.2 MM BTU/HR
250 FT²
CITRATE RECOVERY PUMP
210 GPM
3 BHP
J-11
138,500 LB/HR
CITRATE SOLN
66,200 LB/HR
LIQUID SULFUR
1,998 LB/HR
ASH
286 GPM
2 LIQUID PHASES
SULFUR HEATER
19.75 MM BTU/HR
5970 FT²
C-9
TO F-10
(NEGLIBLE FLOW—NORMALLY 0-25 LB/HR)
SULFUR RECOVERY DRUM
5'Ø x 15'
F-5
L-6 A,B
ASH CENTRIFUGES
75 GPM
60 BHP
700 LB/HR SULFUR
1,998 LB/HR ASH
66,200 LB/HR SULFUR
1,998 LB/HR ASH
75.2 GPM
8900 LB/HR
17.9 GPM
WATER
ASH RESLURRY TANK
4'Ø x 7'
F-13
ASH REMOVAL PUMP
21.8 GPM
0.4 BHP
J-17
DISPOSAL
11,100 LB/HR
(20% SOLIDS)
19.8 GPM
SULFUR REACTOR FEED GAS SECONDARY COOLER
4.25 MM BTU/HR
3980 FT²
C-12
SULFUR REACTOR FEED GAS PRIMARY COOLER
2.4 MM BTU/HR
1780 FT²
C-11
6520 ACFM
6310 ACFM
32.5 PSIA
HYDROLYZER FEED GAS PREHEATER
1.83 MM BTU/HR
3060 FT²
C-7
L: 33,180 LB/HR
V: 11,080 LB/HR
TO F-10
SECONDARY SULFUR CONDENSER
2.45 MM BTU/HR
1750 FT²
C-3
PRIMARY SULFUR CONDENSER
9.68 MM BTU/HR
6460 FT²
C-8
HYDROLYZER
8'Ø x 20'
156 TUBES
24'Ø x 12'
306 CF ACTIVATED ALUMINA
D-6
STEAM 65 PSIA
35,000 LB/HR
2100 ACFM
75,900 LB/HR
15,360 ACFM
SULFUR
F-1
SULFUR SURGE DRUM
4'-6" Ø
9'-6"
34 FWD
248°F
265°F
65,500 LB/HR
73.1 GPM
SULFUR PUMP
92.5 GPM
2 BHP
J-16
29,950 LB/HR
SULFUR
33.3 GPM
54,500 LB/HR LIQUID SULFUR
60.7 GPM
FROM D-4
FROM D-5
VENT
TO C-6
FROM C-6
STEAM DRUM
6'-6" Ø x 13'-0"
F-15
BFW PUMP
230 GPM
3 BHP
J-18
THE M. W. KELLOGG COMPANY
SO2 REMOVAL & RECOVERY
APCO CITRATE PROCESS
4092-50

B


NOTE - EQUIPMENT INSIDE THIS AREA IS PART OF POWER PLANT & NOT TO BE INCLUDED IN ESTIMATE
Reproduced from best available copy.
100 T/HR SILO CONVEYOR V-4
LIMESTONE FROM TRUCKS
F-10 UNLOADING HOPPER 12'x12' SQUARE 45° BOTTOM TROUGH
V-1 FEEDER 100 T/HR
V-3 FEED CONVEYOR 100 T/HR
V-2A&B SOLIDS FEEDERS 50 T/HR EACH
COAL BUNKER
2 629 382 T/YR (WET)
751,250 LB/HR (WET)
715 200 LB/HR (DRY)
PULVERIZER
BOILER
ASH HOPPER
AIR PREHEATER
NOTE - FLOW RATES INSIDE BLOCK FOR 1 OF 6 SIMILAR UNITS
715 GPM
2400 GPM
WATER 367 GPM
SCRUBBERS E-1A,B,C,D,E,F
GAS COOLER
AMMONIA MAKEUP
CLARIFIED WATER 150 GPM 575,000 LB/HR
CLARIFIED WATER PUMP
1450 GPM 60 BHP
SETTLING TANK E-4
SETTLING POND
3096 ACRE FT (FLY ASH)
(POWER PLANT REQUIREMENTS)
854 ACRE FT (GYPSUM)
(PROCESS REQUIREMENTS)
10-YEAR CAPACITY
4050 GPM
545 GPM
COMMON SPARES FOR J-1,2,3-A,B
NOTE - FLOW RATES INSIDE BLOCK ARE FOR 1 OF 2 SIMILAR UNITS
LEGEND


100 T/HR SILO CONVEYOR V-4
F-14 A,B STORAGE SILOS 24'ø x 70'
1 ATM AMB.
V-28
V-5 SILO DISCHARGE CONVEYOR 50 T/HR ρBULK 85 LB/CF
F-12 PULVERIZER FEED DRUM 22'ø x 22'
28,600 LB/HR ρBULK 85 LB/CF
AIR HEATER
MILL
L-3 GRINDING MILL SYSTEM 15 T/HR CAPACITY (INCLUDES ALL EQUIPMENT WITHIN DASHED AREA)
F-13 SOLIDS FEED HOPPER
BIN ACTIVATOR L-4
V-6 WEIGH FEEDER 20,730 LB/HR ρBULK 85 LB/CF
ESTIMATE BY POWER PLANT
3300 BHP (INCREMENTAL) 531M ACFM J-9A,B,C,D,E,F FANS
FROM OTHER 5 TRAINS
STACK
C-2A,B,C,D,E,F
247°F 13.0 PSIA
(%)L = 0.85 20°F
REGEN OVHD CONDENSER C-4
377,550 LB/HR, 336M ACFM, 185°F
95.7 MM BTU/HR 174°F
100,500 LB/HR 190 GPM 174°F 105 SpG
33.5M LB/HR 150# STEAM
170°F
C-7 28.7 MM BTU/HR, 6000 FT²
FEED PREHEATER
7.8 MM BTU/HR, 1500 FT²
C-6 REACTOR OVHD COOLER
187°F
C.W 520 GPM
3,600 ACFM NH3 5864 LB/HR
195°F 388mm Hg
ABSORBER E-2 23'ø-26' 42000 C.F PACKING 3" INTALOX TYPE
187°F 363mm Hg
150# STEAM 43M LB/HR
C-3 REGEN REBOILER 362.7 MM BTU/HR 15M FT²
75 GPM
150# STEAM 30M LB/HR
GROUND CaCO3 20,730 LB/HR
SULFATE REACTOR D-1 12'ø x 12' 60° BTM CONE
2519 GPM 1,534,464 LB/HR (%)L = 0.76
45,460 LB/HR
26,539 LB/HR CaSO4
J-11 REACTOR EFFLUENT PUMP 90 GPM 1.5 BHP
J-10 REGEN EFFLUENT PUMP 3000 GPM 55 BHP
C-8 REGEN EFFLUENT COOLER 106.2 MM BTU/HR 11,000 FT²
C.W 7400 GPM
120°F, 1,531,300 LB/HR 2434 GPM
SULFITE SOLUTION PUMP J-12 210 GPM 2.5 BHP
98% H2SO4 PLANT L-2
570 T/DAY
98% H2SO4
H2SO4 STORAGE TANKS F-9 A,B,C,D,E,F,G 40'ø x 35' HIGH
PRODUCT ACID
H2SO4 LOADING PUMP J-16 460 GPM 20 BHP
SO2 2550 LB/HR AIR 9200 ACFM 1820 A.F.M
J-5 A,B VACUUM PUMP 11,300 ACFM 435 BHP
122°F 324mm Hg 9960 ACFM
SO2 27,300 LB/HR
H2O 3,100 LB/HR
E-3 SO2 STRIPPER 3'6"ø x 12' 45 C.F PACKING 2" INTALOX TYPE
20 PSIA
22 PSIA
DUTY 288M BTU/HR
AIR COMPRESSOR 232.5 SCFM
SEAL DRUM F-6 3'ø x 5' F-7 4'ø x 6'
122°F ATM
SO2 SOLUTION PUMP J-13 540 GPM 7.5 BHP
CLARIFIED WATER 165 GPM
123°F 1 ATM
SLUICE TANK F-8 8'ø x 8' 45° BOTTOM CONE
GYPSUM SLURRY PUMP J-14 260 GPM 5 BHP
J-2 A,B 2800 GPM 52.5 BHP
J-3A,B 548 HP

LEGEND

—x— Reheat Circuit

—•— Fans

Scrubber Circuit

Ductwork

ISSUE ① 4-15-71

	DESCRIPTION	DATE	BY	CHECKED	ISSUED FOR
4	GENERAL	5-9-71	W.B		
3	ADD LIMESTONE SYSTEM	4-21-71	W.B		
2	GENERAL	4-9-71	W.B		
1	GENERAL	3-29-71	W.B.		
	REVISIONS				ISSUED FOR CONSTRUCTION

SCALE NONE
DRAWN
CHECKED
APPROVED C.J.R
DATED
ISSUED FOR FABRICATION

THE M. W. KELLOGG CO.

PROCESS FOR REMOVAL OF SO_2 FROM POWER PLANT STACK GAS BY NH_3 SCRUBBING FOLLOWED BY REGENERATION OF $(NH_4)_2SO_3$ BY DECOMPOSITION OF NH_4HSO_3 WITH HEAT & STRIPPING OF GASEOUS PRODUCTS (ALTERNATE A)

CLASS & ITEM | AREA | JOB NUMBER 4010-50 | DRAWING NUMBER PD-113 D

DRAWING No.

B

TABLE 4

MAGNESIA BASE SCRUBBING

DETAILED COST BREAKDOWN
(All Costs in $M)

Description	Scrubber	Scrubber Circuit	Reheat Circuit	Fans	Ductwork, Valves & Expansion Joints
Major Equipment Cost					
Direct Materials	2,120	2,328	1,643	1,410	1,182
Sub-Contracts	-	1,200	-	-	-
Piping, Elect. & Instr.	-	525	170	195	-
Foundations, Concrete, Steel, Buildings, Paint & Insul.					
Direct Materials	45	92	37	20	23
Sub-Contracts	-	-	20	-	-
Sub-Total Mat'l. &S.C.	2,165	4,145	1,870	1,625	1,205
Other Costs					
Construction Forces, Home Home Office Eng., Proc., Insur., Start-Up & Contractor's Fee	1,295	2,665	860	625	1,115
Sub-Total Investment Cost for Process Plant	3,460	6,810	2,730	2,250	2,320
Other Investment Costs					
Deduct Standard Plant	-	-	-	(1,280)	(1,020)
Net Investment Cost	3,460	6,810	2,730	970	1,300

TABLE 5

WET LIMESTONE SCRUBBING

DETAILED COST BREAKDOWN
(All Costs in $M)

Description	Scrubber	Scrubber Circuit	Reheat Circuit	Fans	Ductwork, Valves & Expansion Joints
Major Equipment Cost					
Direct Materials	2,100	2,360	1,359	1,140	936
Sub-Contracts	-	162	-	-	-
Piping, Elect. & Instr.	-	662	141	143	-
Foundations, Concrete, Steel, Buildings, Paint & Insul.					
Direct Materials	124	141	33	21	17
Sub-Contracts	-	-	20	-	-
Sub-Total Mat'l. & S.C.	2,224	3,325	1,553	1,304	953
Other Costs					
Construction Forces, Home Office Eng., Proc., Insur., Start-Up & Contractor's Fee	1,396	2,805	737	586	857
Sub-Total Investment Cost for Process Plant	3,620	6,130	2,290	1,890	1,790
Other Investment Costs					
Deduct Standard Plant	-	-	-	(1,280)	(1,020)
Net Investment Cost	3,620	6,130	2,290	610	770

TABLE 6

CITRATE PROCESS

DETAILED COST BREAKDOWN
(All Costs in $M)

Description	Scrubber	Scrubber Circuit	Reheat Circuit	Fans	Ductwork, Valves & Expansion Joints
Major Equipment Cost					
Direct Materials	720	1,030	1,798	1,320	1,322
Sub-Contracts	2,748	3,943	-	-	-
Piping, Elec. & Instr.	-	450	186	192	-
Foundations, Concrete, Steel, Buildings, Paint & Insul.					
Direct Materials	44	84	40	19	21
Sub-Contracts	-	-	25	-	-
Sub-Total Mat'l & S.C.	3,512	5,512	2,049	1,531	1,343
Other Costs					
Construction Forces, Home Office Eng.,Proc., Insur., Start-up & Contractor's Fee	1,108	2,418	881	649	1,287
Sub-Total Investment Cost for Process Plant	4,620	7,930	2,930	2,180	2,630
Other Investment Costs					
Deduct Standard Plant	-	-	-	(1,280)	(1,020)
Net Investment Cost	4,620	7,930	2,930	900	1,610

TABLE 7

AMMONIA SCRUBBING (A)

DETAILED COST BREAKDOWN
(All Costs in $M)

Description	Scrubber	Scrubber Circuit	Reheat Circuit	Fans	Ductwork, Valves & Expansion Joints
Major Equipment Cost					
Direct Materials	1,635	1,835	1,341	1,350	972
Sub-Contracts	-	-	-	-	-
Piping, Elect. & Instr.	-	400	140	176	-
Foundations, Concrete, Steel, Buildings, Paint & Insul.					
Direct Materials	87	125	32	20	14
Sub-Contracts	-	-	20	-	-
Sub-Total Mat'l. & S.C.	1,722	2,360	1,533	1,546	986
Other Costs					
Construction Forces, Home Office Eng., Proc., Insur., Start-up & Contractor's Fee	1,198	2,090	707	624	744
Sub-Total Investment Cost for Process Plant	2,920	4,450	2,240	2,170	1,730
Other Investment Costs					
Deduct Standard Plant	-	-	-	(1,280)	(1,020)
Net Investment Cost	2,920	4,450	2,240	890	710